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Anterior subcutaneous internal fixation of the pelvis – what rod-to-bone distance is anatomically optimal?

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Abstract

Introduction Anterior fixation of the pelvis using subcutaneous supra-acetabular pedicle screw internal fixation (INFIX) has proven to be a useful tool by avoiding the downsides of external fixation in patients where open fixation is not suited.

The purpose of this study was to find a rod-to-bone distance for the INFIX that allows for minimal hazard to the inguinal neuro-vascular structures and, at the same time, as little as possible interference with the soft tissues of the proximal thigh when the patient is sitting.

Methods An INFIX was applied to 10 soft-embalmed cadaver pelvises with three different rod-to-bone distances. With each configuration, the relations of the rod to the neuro-vascular and the muscular surroundings were measured in supine and sitting position.

Results Except for the femoral artery, vein and nerve, all investigated anatomical structures of the groin were under compression with a rod-to-bone distance of 1 cm. With a rod-to-bone distance of 2 cm most of the anatomical structures were safe in supine position, although less than with 3 cm. With hip flexion some structures got under compression, especially the lateral femoral cutaneous nerve (LFCN, 80 %) and the anterior cutaneous branches of the femoral nerve (ACBFN, 35 %). With a rod-to-bone distance of 3 cm almost all anatomical structures were safe in supine position, while with hip flexion most superficial structures of the proximal thigh got under compression, especially the LFCN (75 %) and the ACBFN (60 %).

Conclusions Aiming for a rod-to-bone distance of 2 cm is the safest way with regard to compression of the femoral neuro-vascular bundle and at the same time leads to the

least compression of more superficial structures like the LFCN, the ACBFN, or the sartorius and the rectus femoris muscles in sitting position.

Keywords: pelvic fracture; sacral fracture; INFIX; subcutaneous internal fixation; pelvis; elderly.

Level of Evidence: Basic Science Study

Introduction

External fixation has been an established technique for the immediate stabilization of pelvic ring injuries [1, 2].

However, it usually serves only as a temporary stabilization, rolling the patient side-to-side and sitting are limited, and its use is associated with pin tract infections in up to 50 % of cases [3].

Anterior fixation of the pelvis using supra-acetabular pedicle screw internal fixation (INFIX) has proven to be a useful tool in certain situations by avoiding the downsides of external fixation in patients where open fixation is not suited [4-6]. In the authors' experience, the INFIX has been noted to be disturbing for patients when sitting if applied with too much distance from the bone. Other case series pointed out the potential risks associated with placing the rod too close to the bone but also described implant impingement, especially in thin patients [7-9]. Several important neuro-vascular structures are in close vicinity to the connecting rod of this device (Figure 1) and could be injured or compressed with a to small rod-to-bone distance. The femoral artery and vein and the femoral nerve are both running underneath the rod and clinical series have shown an irritation of the lateral cutaneous nerve in up to 27 % of the cases [10-12]. Interference of the rod and the supra-acetabular pedicle screws with the muscles of the proximal thigh in hip flexion has been noted in some patients and could - together with the typical location of the screws - be an explanation for the occurrence of heterotopic ossifications in up to 32 % of the cases [10-12].

While there exist studies investigating the anatomical relations of the rod and the pedicle screws to their surroundings in general [13-15], no study has quantified these relations particular in view of different rod-to-bone distances, so far. Therefore, the

purpose of this study was to find a rod-to-bone distance in anterior subcutaneous internal fixation of the pelvis that allows for minimal hazard to the neuro-vascular and as little as possible interference with the muscular surroundings of the inguinal area. It was our hypothesis that a rod-to-bone distance too small will put the femoral vessels and the femoral nerve under continuous compression in any position, while with a rod-to-bone distance too large, the rod and pedicle screws will interfere with the ilio-psoas muscle in sitting position.

Material and Methods

This study was conducted in accordance with the local laws for body donations and the rules of the institutional donation program

Specimens

Ten cadavers of different size and age (female: 3; all Caucasian; mean donor age: 82 years, range 55 to 100 years; height: 172 cm, range 153 to 180 cm; weight: 76 kg, range 50 to 95 kg) with 20 groins were used for this study. All cadavers had undergone soft-embalmment as described by Thiel [16]. The advantage of embalmment with Thiel's solution is the ability of this technique to preserve the tissues' color, consistency, and transparency to a high degree without the risk of decomposition [17]. The INFIX was then applied percutaneously through two small supraacetabular incisions of 2 cm length as previously described [4-6]. An 8.0 mm-pedicle screw of 80 mm length was placed bilaterally into the supraacetabular osseous canal at the level of the anterior inferior iliac spine (AIIS). Both screws were connected by a 5.5 mm-rod

that was inserted subcutaneously anterior to the symphysis (VIPER, Sacro-Alar-Iliac Fixation system, DePuySynthes, Zuchwil, Switzerland). The rod was pre-bent before attachment into the screw heads and fixed with its curvature in the plane of the screw shafts (Figure 1).

The skin was then removed from the inguinal region and the anatomic assessments and pressure measurements were performed as described below. Care was taken to remove as little surrounding soft tissues as possible.

The INFIX pedicle screws were consecutively inserted with different rod-to-bone distances at the level of the supra-acetabular pedicle screw of 1 cm, 2 cm, and 3. With each configuration, the relation of the rod to the neuro-vascular and the muscular surroundings will be described and measured, once in supine and once in sitting position of the cadaver. The changes in compartmental pressure inside the muscular and the vascular lacunae were measured with both positions.

Each groin measured separately.

Anatomical measurements

After skin removal, the shortest anatomical distances between the implant rod and the femoral artery, vein and nerve, the lateral femoral cutaneous nerve (LFCN), the anterior cutaneous branches of the femoral nerve (ACBFN), and the sartorius and rectus femoris muscle were measured by the use of a vernier calliper (Helios Preisser, Gammertingen, Germany) by the same person. These measurements were done on each side once in supine (hip extended to 0°) and once in sitting position (hip flexed to 90°) and repeated for each of the three rod-to-bone distances. In addition, the distance between the screw shafts and the LFCN, the sartorius muscle and the rectus

femoris muscle were measured in supine position. All measurements were performed by one of the authors (JS) who had practiced and standardized the measurement technique during preliminary tests on two other cadavers. During these preliminary experiments, it was evaluated whether there were relevant differences between sitting and hip flexion in supine position for the observed anatomical distances in the inguinal area. In the two cadavers for preliminary testing, the differences for the distances between rod and femoral neurovascular bundle showed to be less than 2 mm when comparing real sitting to just flexing the hip.

Pressure measurements

For pressure measurements, balloon tamps connected to a manometric device from a kyphoplasty system (KyphX-Systems, Kyphon, Medtronic, Fridley, MN, USA) were introduced into the *Lacuna vasorum* and *Lacuna musculorum*. The pressure measurements were performed before skin removal in the inguinal area. The abdominal wall was opened cranial to the inguinal ligament without opening of the peritoneal cavity. First, the *Lacuna vasorum* was carefully dissected digitally in distal direction and the balloon was positioned under sight into the subinguinal fossa (Figure 2). The differences in balloon pressure in supine and in sitting position of the cadaver were documented. the same procedure was then repeated for the *Lacuna musulorum.*

Descriptive anatomy

In addition to the quantitative measurements, the anatomical relations of the screw and the rod in context to the surrounding anatomical structures and layers were described (e.g. the spermatic cord, presence of inguinal hernias, etc.).

Statistical analysis

Statistical analysis was done by the use of SPSS for windows 22.0 (SPSS, Chicago, Illinois, USA). Metric data was processed using a One-Way ANOVA with Bonferroni corrections for comparisons of anatomical and pressure measurements between the three rod-to-bone distances. Differences were considered significant for values of $p < 0.05$. Results are presented as mean and standard deviation (SD).

Results

Anatomical measurements

Absolute distances between the implant rod and anatomical structures are listed in Table 1.

In supine position with the hips extended, an increase of the rod-to-bone distance was associated with also an increase of the distances between the rod and the anatomical structures of the groin. With the hips flexed, however, increasing the rod-to-bone distance lead to more compression due to the progressive protrusion of the INFIX into the soft tissues of the proximal thigh.

In order to better account for the cadavers' differences in size and physique, rather than comparing absolute measurements, we calculated the percentages of groins where the measured anatomical structure was in vicinity of less than 3 mm to the implant rod (Figure 3). A distance of less than 3 mm was thought to represent an increased risk for compression of the respective anatomical structure as often small amounts of surrounding fat had to be removed to dissect the nerves and vessels.

Except for the femoral artery, vein and nerve, all investigated anatomical structures of the groin were under compression with a rod-to-bone distance of 1 cm in supine position (Figure 4 A). In sitting position with the hip flexed, even the femoral artery, vein and nerve were in close vicinity to the implants in some samples.

With a rod-to-bone distance of 2 cm most of the anatomical structures were safe in supine position (Figure 4 B), although less than with 3 cm. With hip flexion some structures got under compression, especially the LFCN (80 %) and the ACBFN (35 %).

With a rod-to-bone distance of 3 cm almost all anatomical structures were safe in supine position (Figure 4 C), while with hip flexion most superficial structures of the proximal thigh got under compression, especially the LFCN (75 %) and the ACBFN (60 %).

The sartorius muscle was compressed in almost all of the samples, especially when the hips were flexed or in supine position when the rod-to-bone distance was 1 cm. The rectus femoris muscle was only very rarely compressed in both positions and only with a rod-to-bone distance of 1 cm.

However, 80 % (4/20) of the screws perforated the sartorius muscle and all screws (20/20) perforated the rectus femoris muscle or at least its tendon's origin. If not perforated by a screw, the sartorius muscle was always at least touching it. Seven screws (35 %) were in close vicinity (less than 3 mm) to the LFCN.

Pressure measurements

The change of pressure with sitting was calculated by subtracting the pressure measured in supine position from the pressure measured in sitting position.

In the *Lacuna vasorum,* the balloon pressure when sitting up increased by 107 mbar (SD 76 mbar) with a rod-to-bone distance of 1 cm, by 38 mbar (SD 52 mbar) with 2 cm, and by 21 mbar (SD 51 mbar) with 3 cm.

In the *Lacuna musculorum,* the balloon pressure when sitting up increased by 152 mbar (SD 124 mbar) with a rod-to-bone distance of 1 cm, by 52 mbar (SD 67 mbar) with 2 cm, and by 31 mbar (SD 42 mbar) with 3 cm.

In both compartments, there was a significantly smaller increase of balloon pressure when sitting up with an INFIX applied in 1 cm rod-to-bone distance when compared to the configurations with 2 or 3 cm (Figure 5).

Descriptive anatomy

Even though in close anatomical proximity, the rod did not injure the spermatic cord in any of the male cadavers (Figure 6 A). The skinnier the cadaver, however, the closer to the spermatic cord the rod had to be placed subcutaneously.

Especially in skinny patients, the rod protruded more prominently the greater the rod-to-bone distance was. With a rod-to-bone distance of 3 cm, this lead to noticeable tenting of the skin in non-obese patients.

Two cadavers had right-sided inguinal hernias, that again both were not injured by the rod but were in close anatomical vicinity to it (Figure 6 B).

As the LFCN often ran laterally to the screws it was sometimes only compressed by the part of the rod jutting out the screw head laterally (Figure 6 C). In these cases, compression of the nerve could have been avoided by choosing a shorter rod with less overlap.

While it was unavoidable to perforate the rectus femoris muscle or at least its tendon when placing screws into the supraacetabular bone, it was often possible to palpate the sartorius muscle after the skin incision was made and then to insert the screw just next to the muscle.

Discussion

The purpose of this study was to find a rod-to-bone distance in anterior subcutaneous internal fixation of the pelvis that allows for minimal hazard to the neuro-vascular and as little as possible interference with the muscular surroundings of the inguinal area. As it was our hypothesis, we observed more compression of the anatomical structures of the groin with a rod-to-bone distance too small (i.e. 1 cm) in any position and increased compression due to the progressive protrusion of the INFIX with a rod-to-bone distance too large (i.e. 3 cm). In line with these topographic findings, we observed significantly higher balloon pressure changes in the vascular and muscular *lacunae* of the groin when the rod-to-bone distance was too small.

With the three distances investigated in this study, it seems that an INFIX with a rod-to-bone distance of 2 cm is associated with the least compression of inguinal structures in both sitting and supine position.

Even with a rod-to-bone distance of 1 cm the greater neuro-vascular structures (femoral n., a., v.) were never close proximity to the rod in supine position and only very rarely in sitting position. In their anatomical study based on CT scans in supine position of 13 patients with an INFIX, Merriman et al. [15] observed an average distance from the vascular bundle to the connecting rod of 2.2 cm. This is more than our results for a rod-to-bone distance of 1 cm and less than our results a rod-to-bone distance of 2 cm and, thus, consistent with their reported “screw out bone” distance of 1.8 cm. A recent anatomical dissection study by Apivatthakakul and Rujiwattanapong [13] found average distances between rod and femoral nerve (12.5 mm), femoralartery (12.8 mm) and femoral vein (13.5 mm) that were very close to the measurements of

this study, but the authors did not differentiate their results for different rod-to-bone distances.

Neither Merriman et al. nor any of the other clinical INFIX cohort studies reported problems with femoral vascular compression [4, 8, 10-12]. Although the surgeon must keep these structures in mind when inserting the rod subcutaneously, it seems that compression of the femoral neuro-vascular bundle is less of a concern once the INFIX is applied with a rod-to-bon distance of about 2 cm.

Clinical studies rather point to the fact that stabilization of pelvic ring injuries with an INFIX is often associated with postoperative irritation of the LFCN in up to 27 % of the cases [8, 10-12]. In the authors' own experience, the patients often experience pain in the anterior region of the thigh when sitting. All these complaints are well explained by the compression of the ACBFN and the LFCN seen in sitting position of the cadavers in our study. Even though not a major complication, pain and paraesthesia in the thighs are frequently the reason why patients ask for early removal of the INFIX. It seems that a rod-to-bone of 2 cm (less compression of the ACBFN when sitting) and a rod with as little lateral overlap as possible (less avoidable affection of the LFCN) might help to reduce the rate of these complications.

It remains unclear whether the high occurrence of heterotopic ossifications in up to a third of the patients [10-12] is rather related to the direct injury of the screws perforating the rectus femoris and the sartorius muscle or to compression by rod. If rod compression is the problem, a rod-to-bone distance of 2 cm would again be favourable. If it is the direct injury from the screws, the surgeon would be advised to palpate and spare the sartorius muscle when placing the screws.

A common limitation of morphometric cadaver studies is the often relatively small sample size due to the limited availability of cadavers. This makes the results vulnerable for confounding factors like donor height and weight or individual anatomic variability. In addition, removing the skin and some of the superficial soft tissues to allow for direct anatomical measurements may have changed the pattern of evasion or deflection of vessels and nerves when being affected by the rod or flexion of the hip.

The alternative would have been to do morphometric measures based on 3D imaging like CT or MRI scans in a large number of real patients with an INFIX [15]. The advantage of a cadaver study, however, is the fact that different rod-to-bone distances can be compared in the same body. This would not be possible in real patients.

Using soft-embalmed cadavers [16] with a consistency very similar to the living anatomy we were able to observe dynamic changes which would have been very difficult when using 3D imaging. The same accounts for pressure measurements in the vascular and muscular *lacunae*, although it has to be clear that the absolute measurements of balloon pressure do not represent the intracompartmental pressures in a living person. Yet, the changes in balloon pressure should provide an indication of the different pressure patterns under different external conditions like compression by an INFIX rod.

For this study, rod-to-bone distances of 1 cm, 2 cm, and 3 cm were chosen. This selection is somewhat arbitrary but in the range of what seems clinically logical and what is reported in the literature [15]. These distances can be easily measured using a K-wire that is introduced into surgical wound until it touches bone and then can be measured at the level of the screw head. It may well be, however, that a distance

between 2 cm and 3 cm is superior and it is very likely that the perfect distance will change with the patient's size and individual anatomy. It must be mentioned that also the curvature and the tilt of the rod can affect the amount of free space below it and that these factors were not assessed in this study.

Hence, future studies may focus on the role of individual patient-related anatomical factors and the configuration of the rod itself [14].

Until then, it remains unknown to the surgeon in the operating room how these potential confounders may influence the optimal distance. Thus, this study sought to find a rod-to-bone distance that is at the same time safe with regard to the greater neuro-vascular bundle and can reduce harm to the smaller structures in all patients.

Conclusion

Based on this *ex vivo* anatomical model and with the limitations mentioned above in mind, aiming for a rod-to-bone distance of 2 cm when applying an INFIX is the safest way with regard to injury to the femoral neuro-vascular bundle and at the same time leads to the least compression of more superficial structures like the LFCN, the ACBFN, or the sartorius and the rectus femoris muscles. Sparing the sartorius muscle when placing the supraacetabular screws and using a rod with as little lateral overlap over the screw heads as possible avoids irritation of the muscle and the LFCN.

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Figure legends

Figure 1 The INFIX

(A) Anatomical relations of the INFIX. FIP: iliopsoic fascia. IL: inguinal ligament. AIIS: anterior inferior iliac spine. LCFN: lateral cutaneus femoral nerve. ACBFN: anterior cutaneous branches of the femoral nerve. FA: femoral artery. FV: femoral vein. SC: spermatic cord. FN: femoral nerve. SM: sartorial muscle. ASIS: anterior superior iliac spine. (B) Antero-posterior pelvic radiograph showing the clinical application of the INFIX and demonstrating the relation of the INFIX to the osseous pelvis with insertion of the screws at the level of the AIIS (d: rod-to-bone distance). (C) Percutaneous application of the INFIX.

Figure 2 Pressure measurements

A balloon tamp (BT) connected to a manometric device was inserted into either the *Lacuna vasorum* or the *Lacuna musculorum* underneath the inguinal ligament through a suprainguinal approach and balloon pressures were measured in supine and sitting position.

FIP: iliopsoic fascia. IL: inguinal ligament. BT: balloon tamp. FN: femoral nerve. IB: iliac bone. IPM: iliopsoas muscle. EOM: external oblique abdominal muscle.

Figure 3 Anatomical measurements - results

The graphs show the percentages of specimens' groins where the distance of the stated anatomical structure to the implant rod was less than 3 mm in supine (hip extended -blue) and sitting (hip flexed - orange) position.

Figure 4 Compression of inguinal structures with different rod-to-bone distances

INFIX configurations with a rod-to-bone distance of 1 cm (A), 2 cm (B), and 3 cm (C). A.,V.,N.: Femoral artery, vein, and nerve. *: LFCN. †: ACBFN.

Figure 5 Pressure measurements - results

Graph showing the changes of balloon pressure in the *Lacuna vasorum* (A) and the *Lacuna musculorum* (B) when flexing the hips to 90 ° (supine to sitting position).

Figure 6 Anatomic relations

Relation of the rod to the spermatic cord (A, right groin of a male cadaver) and an inguinal hernia (B, right groin of a male cadaver). (C) shows the LFCN running underneath a laterally overlapping rod, being compressed by it.